Trenchless Methods for Pipeline Construction

PRESENTATION TO PIPELINERS CLUB OF ATLANTA | NOVEMBER 2017

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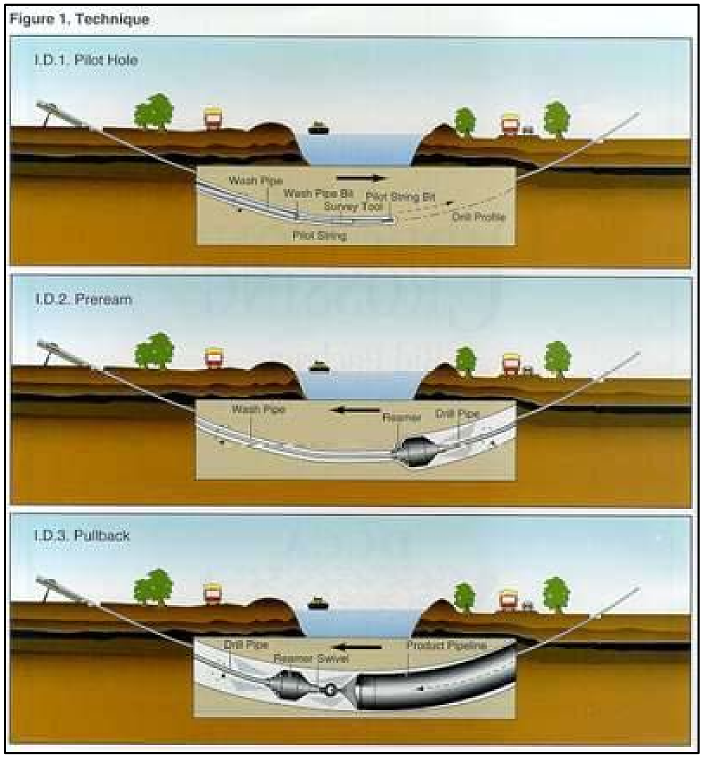
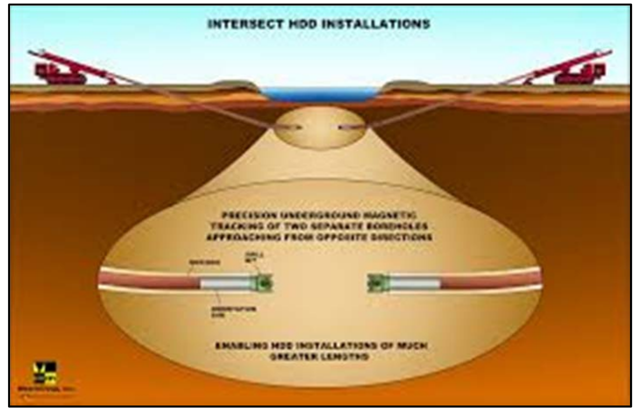
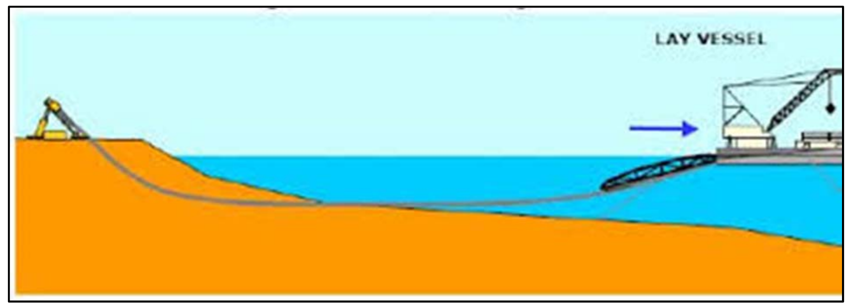
State-of-the-Industry for Trenchless Pipeline Construction

1. Trenchless Techniques Overview
   i. Horizontal Directional Drilling – HDD
   ii. Micro-Tunneling
   iii. Direct Pipe®
   iv. Jack & Bore and Other Guided-Bore Techniques
2. The School of Mud
   1. Inadvertent Returns (Frac-Outs) of Drilling Muds

Horizontal Directional Drilling







- In use since early 1980s; significant improvements over time
- Three step method: pilot hole / reaming & conditioning / product pipe pullback
- Works with steel, PVC, DI, and HDPE materials; Typical diameters 2” to 60”
- Longest lengths exceed 8,000’ / Intersect method* > 12,000’
- Versatile - accurate steering & monitoring; vertical and horizontal curves
- Borepath length & geometry are controlled by product pipe properties & obstacle crossed
- Handles most geologic conditions ***except*** loose granular materials, karst, soft cohesive soils

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HDD Drill Entry Side Layout

- Entry side requires area for staging equipment;
  usually a minimum of 100'x150' is necessary for large HDD installations
- Key equipment: drilling machine, drill pipe, mud pump, fluid system and tank, power unit and controls, storage of bentonite mud, tools and spare parts, mud return pit
- Consideration should be given to maintaining access for semi-trucks and construction equipment; cranes and excavators will need to maneuver in the workspace

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HDD Drill Exit Side Layout

- The drill exit side is where the product pipe will be fabricated and pulled into place
- Typical pipe stringing area = 50'; wide enough to allow pipe fabrication & testing
- Ideal length = long enough to fabricate the entire section of the HDD
- If space is limited, fabricate in sections and pull-back in series
- Mud pit is typically dug to catch drilling fluid returns
- Cranes & backhoes + guides typically used to position pipe for pullback
- Roller guides reduce friction during pullback

HDD Design Approach

- Engineered Design versus Contractor Design/Construct
- Engineered design needed when Owner competitively bids project - provides uniform bidding platform
- If Engineered Design, designer must transfer liability of HDD completion – done by clauses in the Contract Documents
- Some Owners have a preferred driller – work with them on design and negotiate cost
- Pipe stress calculations for installation and operation

ANALYSIS OF INSTALLATION LOADS AND STRESSES - PRCI METHOD

10 In. (250mm) Nominal Steel - X-42 (.365" wall) - Brisbane River - HDD

URS Virginia Beach — *Monday, March 10, 2014*

Pipe Material Properties			Installation Properties		
Pipe Outside Diameter (D):	10.00	in	Coeffecient of Friction (μ_{soil}):	0.30	
Minimum Wall Thickness (t):	0.365	in	Fluid Drag Coefficient (μ_{mud}):	0.06	psi
Modulous of Elasticity (E):	2.9E+07	psi	Drilling Mud Density (γ_{mud}):	89.80	lb/ft^3
Spec. Min. Yield Strength (SMYS):	42,000	psi	Water Density (γ_{wa}):	62.40	lb/ft^3
Bending Moment of Inertia (I):	128.21	in^4	Ballast Weight (W_b):	29.25	lb/ft
Poisson's Ratio (v):	0.30	steel	Displaced Mud Weight (W_m):	48.98	lb/ft
Dia. to Wall Thickness Ratio (D/t):	27.40		Effective Wgt Ballasted (W_e):	17.83	lb/ft
Coeffecient of Thermal Expansion:	6.5E+06	in/in/F	Effective Wgt Submerged (W_s):	-11.42	lb/ft
Empty Pipe Weight:	37.56	lb/ft	Above Ground Load (W_p):	30,484	lb
Pipe Interior Volume:	0.47	ft^3/ft	Allowable Pull Force :	1.86E+06	Newton
Pipe Exterior Volume:	0.55	ft^3/ft	Pipe Face Area (A):	11.05	in^2
			Hydrokinetic Pressure (p):	10.00	psi
			Hydrokinetic Force (F_{HK}):	1178.10	lb

Drilled Path Input

Sta. Drill Entry:	000+00	Drill Entry Angle:	12	°
Elev. Drill Entry:	6.56	Entry Tangent:	338	ft
Elev. Bottom:	-85.22	Radius Entry Curve:	984	ft
Sta. Drill Exit:	040+40	Bottom Tangent:	2,970	ft
Elev. Drill Exit:	6.56	Radius Exit Curve:	984	ft
Elev. Obstacle:	-45.54	Exit Tangent:	338	ft
Clearance Check:	OK >5'	Drill Exit Angle:	12	°
Horizontal Curve?:	YES	Horizontal Curve Radius:	984	ft
		Horizontal Curve Entry Angle:	15	°
		Horizontal Curve Exit Angle:	15	°

Drilled Path Geometry

	Entry	VPC1	VPT1	HPC1	HPT1	VPC2	VPT2	Exit
Elevation	6.56	-63.71	-85.22	-85.22	-85.22	-85.22	-63.71	6.56
Station	0000+00	0003+31	0005+35	0030+16	0033+73	0035+05	0037+10	0040+40
Total Drill Length	0.00	338.00	544.09	3016.08	3373.39	3514.09	3720.18	4058.19

Pull Back Forces (SI Units)

	Above Ground Load	Frictional Drag	Fluidic Drag	Axial Segment Weight	Bending Frictional Drag	Assumed Tension	Average Tension	Section Pull Back	Total Pullback (Newton)
Point 1	135,601	5,038	34,009	3,570	\	0	0	178,218	183,459
Point 2	\	\	20,736	1,094	19,950	200,170	204,349	41,780	225,239
Point 3	\	2,097	14,156	\	\	0	0	16,253	241,493
Point 4	\	\	35,952	4,698	11,567	262,445	267,601	52,216	293,709
Point 5	\	37,669	248,723	\	\	0	0	286,392	580,101
Point 6	\	\	20,736	-1,094	47,553	609,406	613,698	67,195	647,296
Point 7	\	5,038	34,008	-3,570	\	0	0	35,477	682,773

Brisbane River, Caltex Crossing
10" Petroleum Pipline

3.28 800.00 243.84 249.94

Date:	3/10/2014
Material:	Steel
DR:	
OD (in):	10.00
t (in):	0.37
Avg ID (in):	9.27
Weight (lb/ft):	37.56

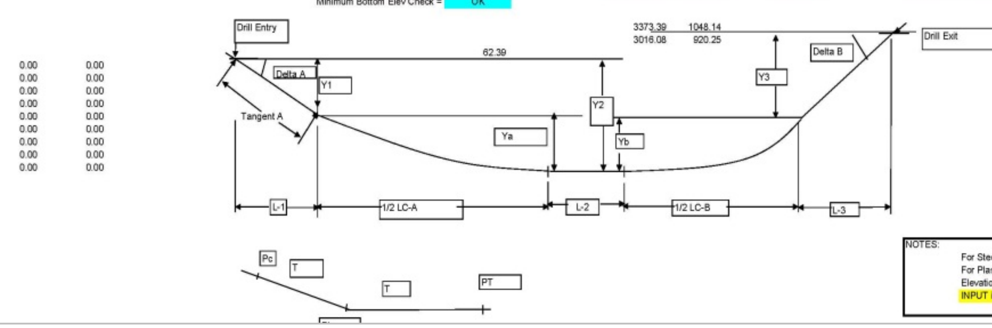
Brisbane River Crossing	(FT)		(Meters)
Entry Ground Elevation	6.56		2.00
Exit Ground Elevation	6.56		2.00
River Bottom	-42.59		-12.98
Min. Depth below River Bottom	37.73		11.50
Min. T.O.P. Elevation	-80.31		

Pt.	Sta.	Elev.
Entry 12'	00+00.0	2.0
PC1	01+00.8	-19.4
PT1	01+63.1	-26.0
HPC1	09+20.3	-26.0
HPT1	10+48.1	-26.0
PC2	10+68.4	-26.0
PT2	11+30.8	-19.4
Exit 12'	12+31.5	2.0
Radius	300.0	Meters
Horiz. Dist	1231.5	Meters
HDD Length	1236.9	Meters

820.21

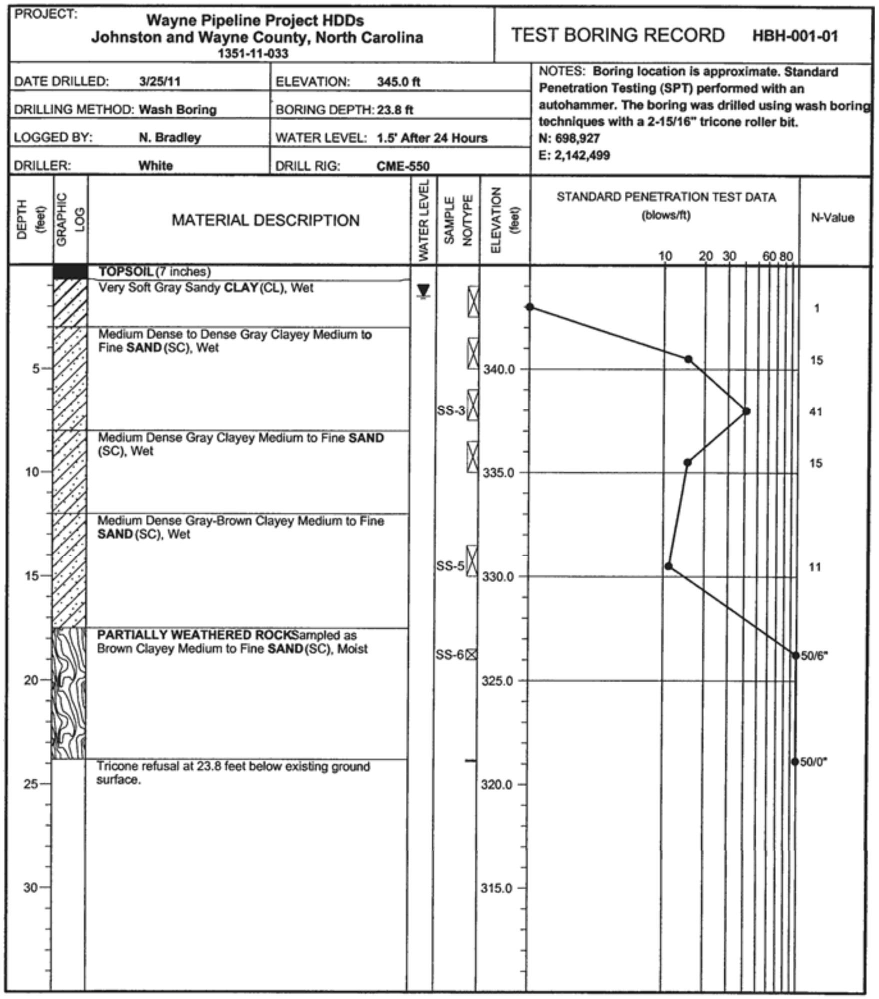
Pipe Type	Size	R	Delta A	radians	Tangent of A	y1	T1	L-1	1/2 LC-A	ya	y2 (max depth)	B.O.P. Elev @ Bottom	L-2 (bottom flat section)	Delta B	radians	1/2 LC-B	yb	y3	T2	L-3	Total Horiz. Length	ARC-A	ARC-B	Tangent of B	Total Length Along C/L
Carrier	10.00	984	12.0	0.209	338.0	70.27	103.4	330.61	204.6	21.5	91.8	-85.64	2970.0	12.0	0.209	204.6	21.5	70.3	103.4	330.6	4040.5	206.10	206.10	338.00	4058.2
Cumulative Distance		300						331	535				3505			3710				4041					
Stationing								0003+30.61	0005+35.25				0035+05.25			0037+09.89				0040+40.50					
Pipe Centerline Elevation								-63.71	-85.22				-85.22			-63.71				6.56					
Pipe Crown Elevation								-63.30	-84.80				-84.80			-63.30				6.98					

Minimum Bottom Elev Check = OK



NOTES:
For Steel Pipe Minimum bending radius =100*Diameter (i
For Plastic Pipe set minimum bending radius to 50 feet *
Elevation of pipe refers to the top crown elevation
INPUT in Yellow Cells

Subsurface Conditions



- Geotechnical investigation to determine subsurface conditions – key for construction risk and mitigation strategies
- Borings located at the entry and exit points + spaced along drill length
- Geologic survey should include: Soil Classification, Standard Penetration Test, Gradation Curves
- In rock - survey should include cored samples with unconfined compressive strength, Mohs Hardness, RQD, % Recovery
- Loose soils, running sands make borehole stability more difficult; large cobbles and boulders can be show stoppers

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HDD Design Challenges

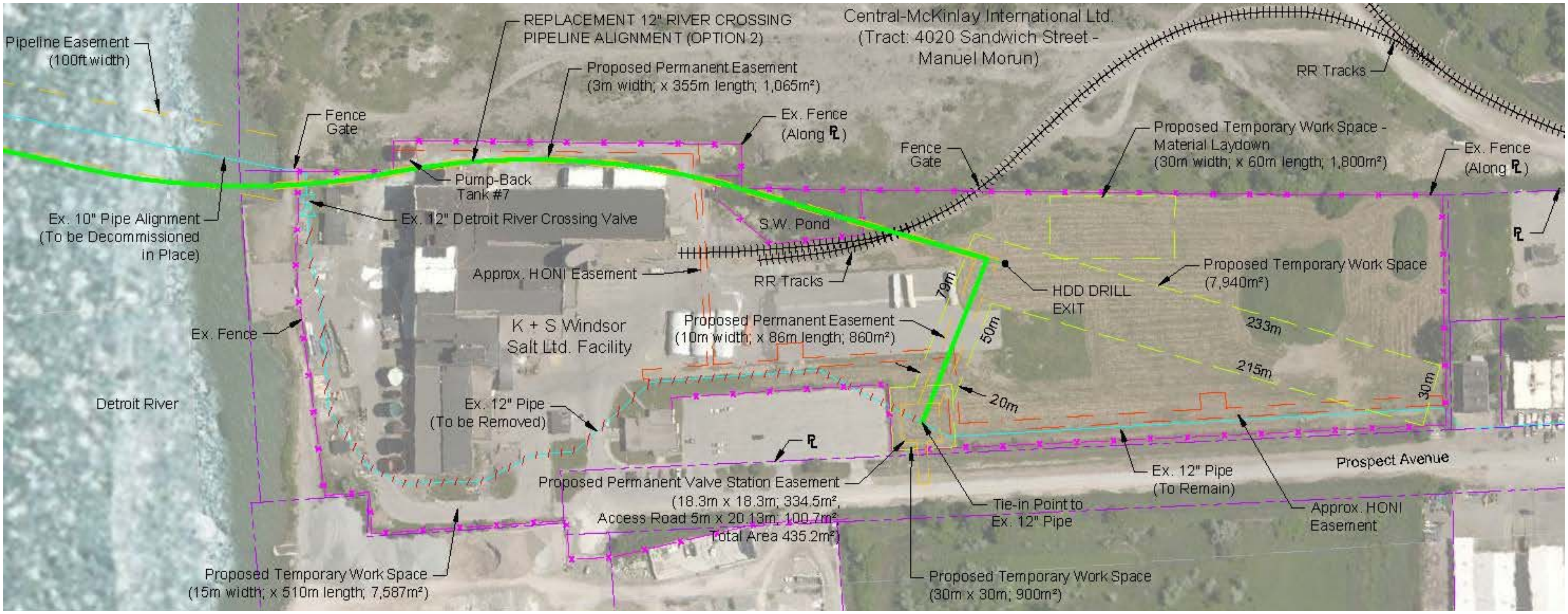
The "Ideal" HDD:

- Straight line from entry to exit
- Two vertical curves
- Radius of curvature per industry guidelines
- Typical entry/exit angles: 8° - 16°
- Under all obstacles with adequate clearances

Detroit River Crossing

- New pipeline proposed under Detroit River
- Tie-in to existing U.S. valve station
- New valve station on Canadian side

HDD Design Challenges



Detroit River Crossing

- Required to stay on one property
- Resulting alignment must have multiple horizontal & vertical curves
- Avoid structure foundations and salt cavern sink hole / buried building
- Limited pull-back work space will require 6 pipe sections

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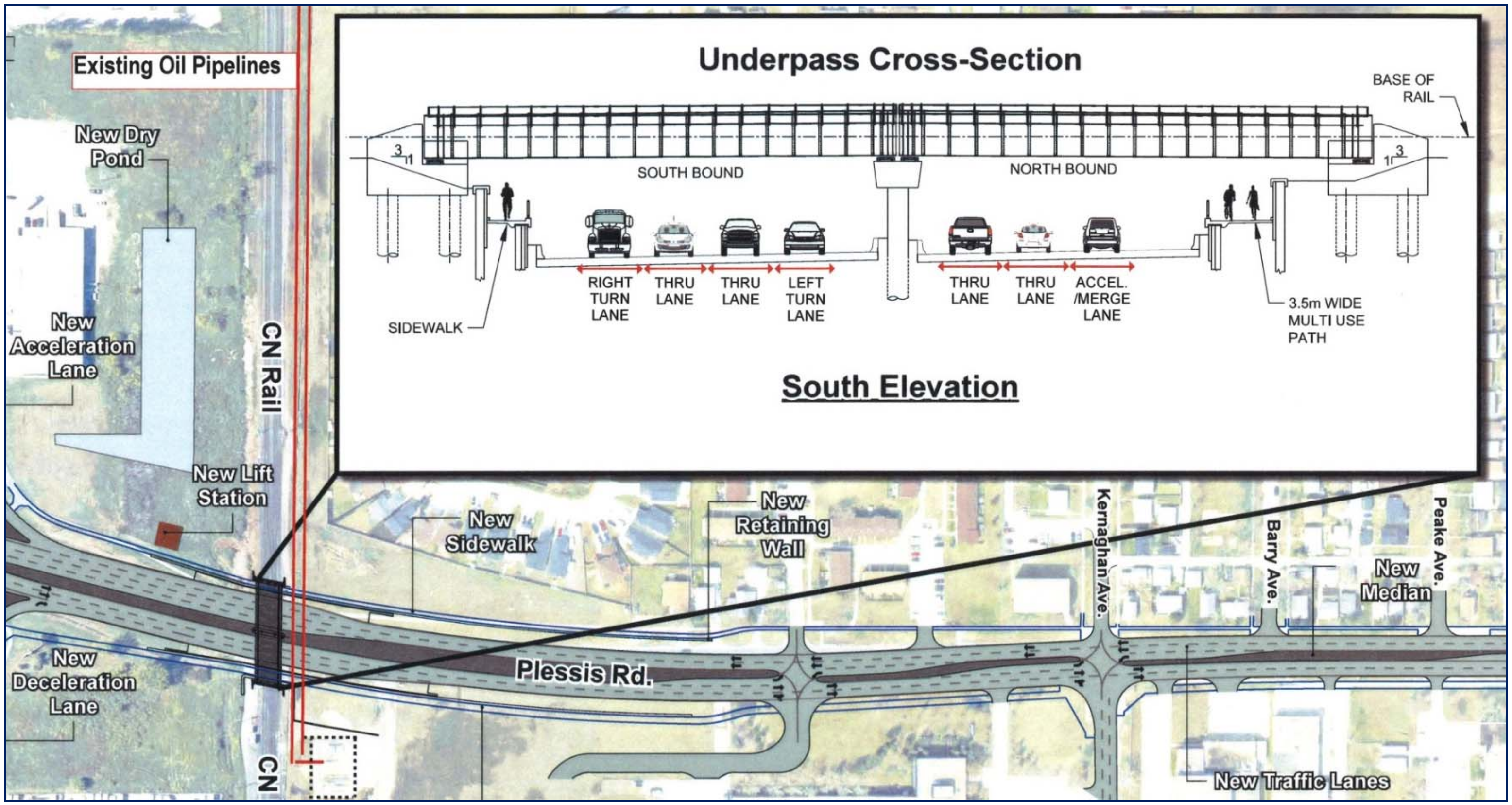
HDD Design Challenges

Winnipeg, Manitoba - CN Rail Grade Separation Project

- Relocate Two 8-Inch Oil Pipelines
- Tie-in to Valve Station & Down-stream Lines
- Coordinate Pipeline Relocation with Underpass Construction and Ancillary Improvements



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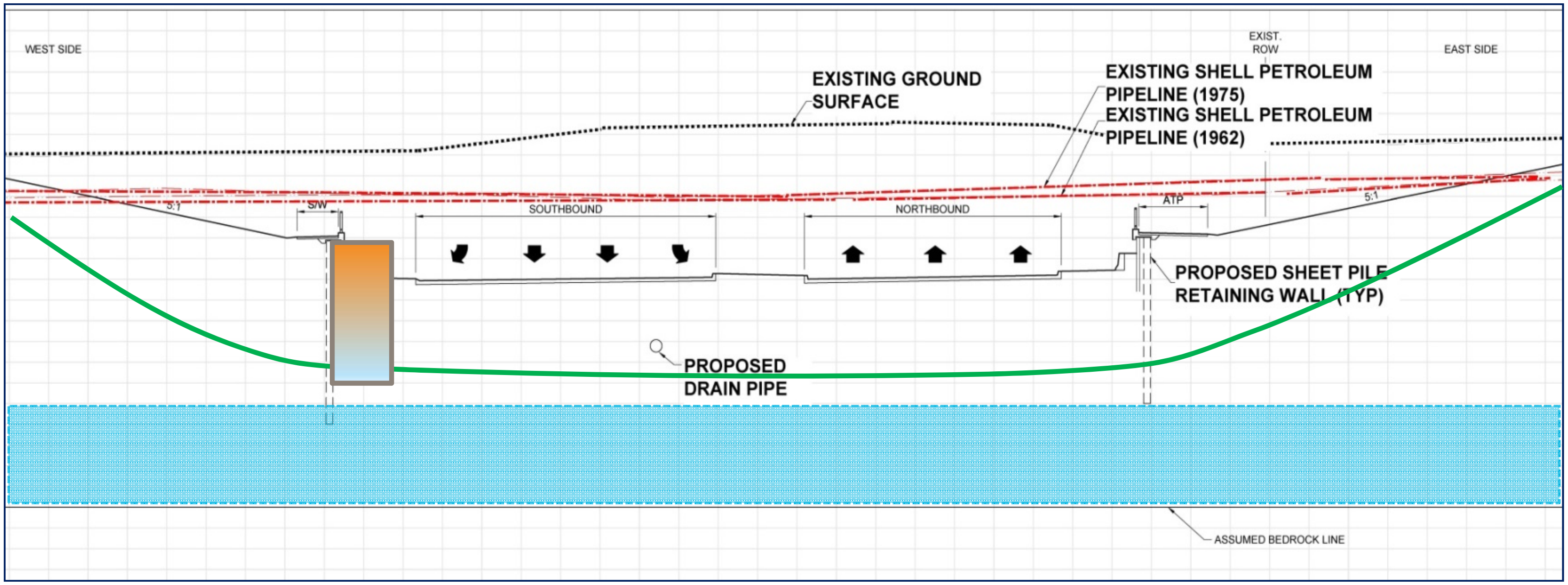
HDD Design Challenges



Winnipeg, Manitoba - CN Rail Grade Separation Project

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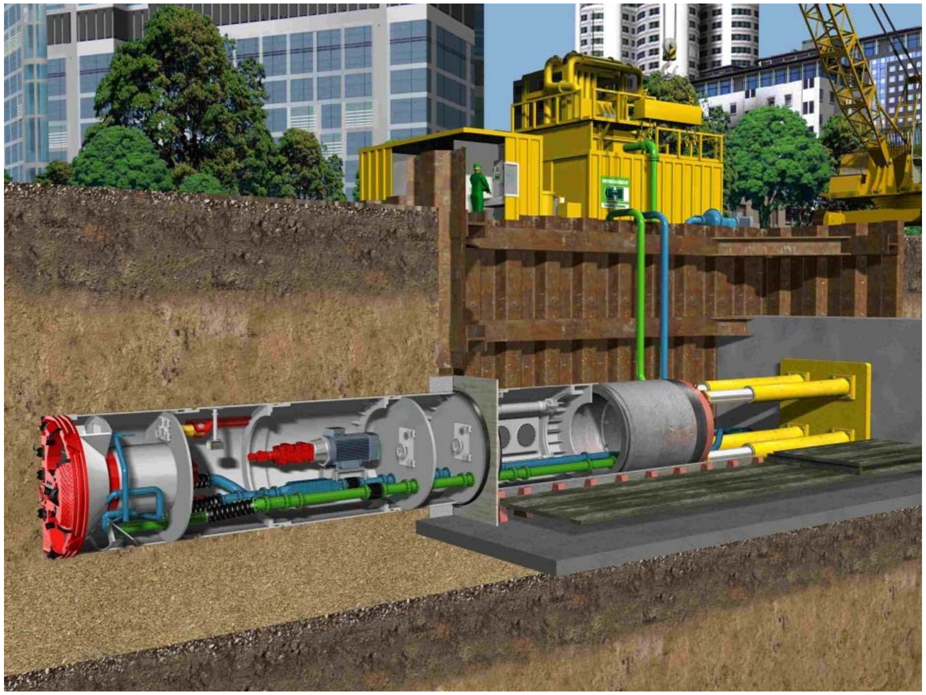
Micro-tunneling

- Uses a remote controlled, steerable, micro tunnel boring machine (MTBM) with jacking for forward motion
- Requires launch and receive shafts/pits at required pipe depth
- Works with steel, DI, PVC, clay pipe; typical diameters from 24" to 96"
- Max length depends on geology - range of 1,500' to 2,000' achieved
- Cutter faces for soft ground, mixed ground and rock, above and below water table
- Maintains pressure against soil face to prevent caving
- Suitable for gravity pipelines requiring precise line and grade even in poor soil conditions



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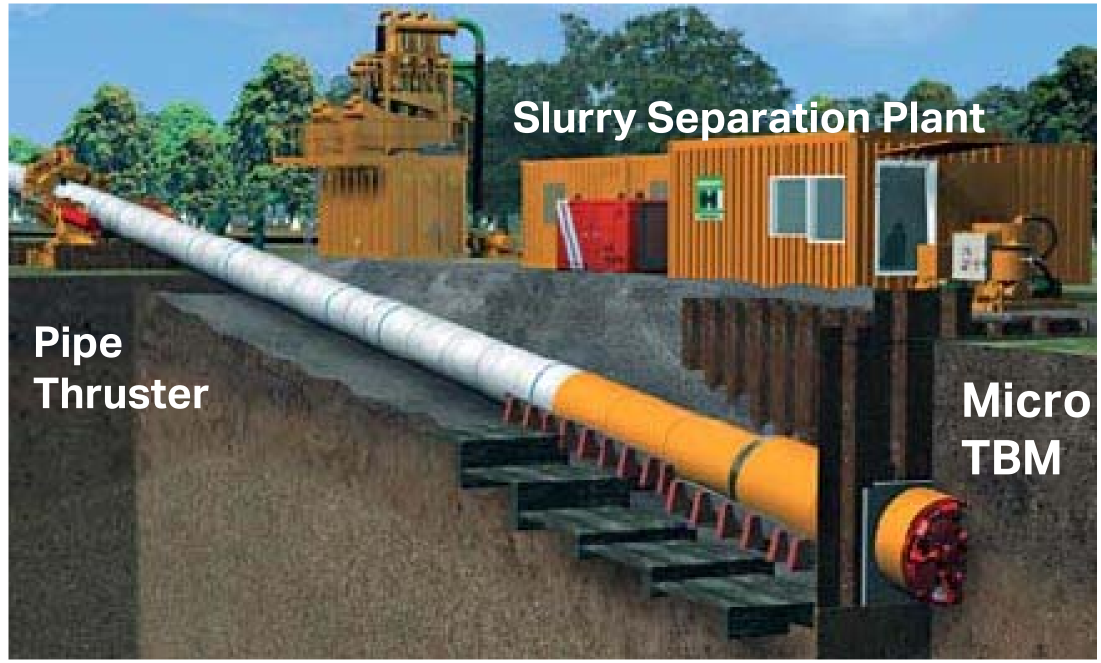
Direct Pipe®

- Combines the methods of micro-tunneling and HDD
- Uses a micro TBM to remove soil and steer
- Spoils and slurry removed via closed circuit lines laid in product pipe
- Pipe thruster works with 20″ - 60″ steel pipe; 5° – 15° angles
- Typical max length is 4,500′
- Single-step method for fast installation of piping
- Handles wide range of geologic materials including gravel/cobles
- Smaller space needs then HDD



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Jack & Bore

- Widely used, reliable, relatively inexpensive method
- Requires launch and receive pits at required pipe depth
- Spoils removed by auger bit inserted in casing pipe / product pipe; hydraulically pushed-in from behind
- Works with steel pipes typically 6″ to 60″ diameter
- Typical max lengths to 400′ depending on soil conditions and pipe size
- Can install casing pipe or product pipe
- Can be used in both granular and cohesive soils; not applicable to rock

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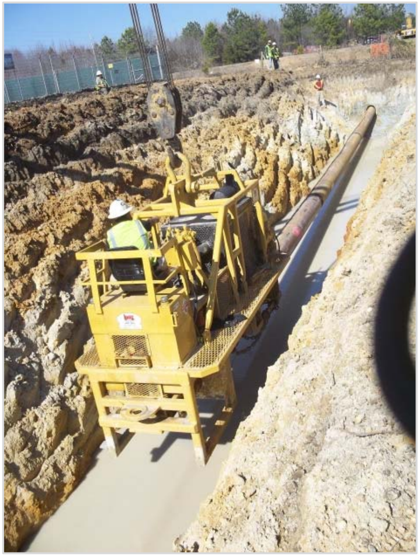
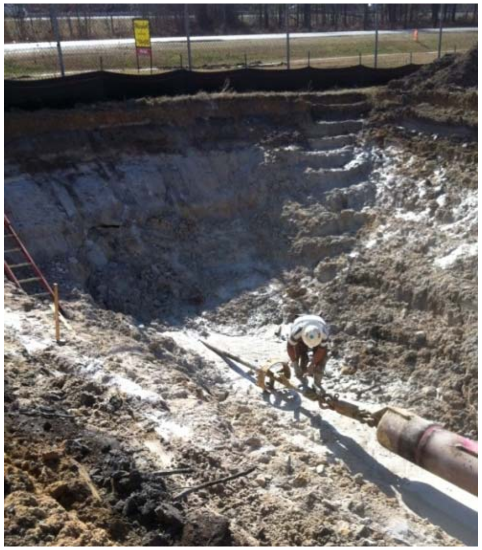
Other Guided Bore Techniques

- Various hybrid methods used by contractors
- Typically use a pilot bore followed by hole enlargement and pipe installation via push or pull methods

I-95 Crossing, Wilson, NC

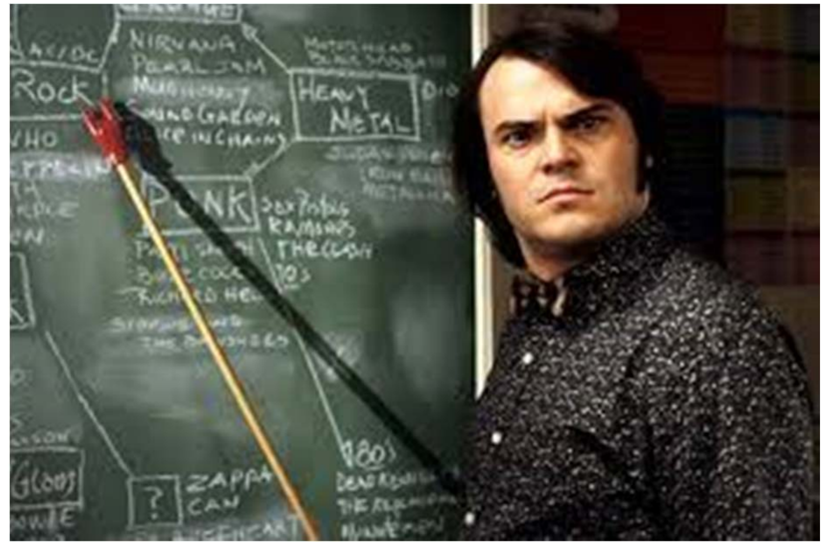
- Laney method using excavated trench and suspended drill unit
- Product pipe pushed into hole behind auger



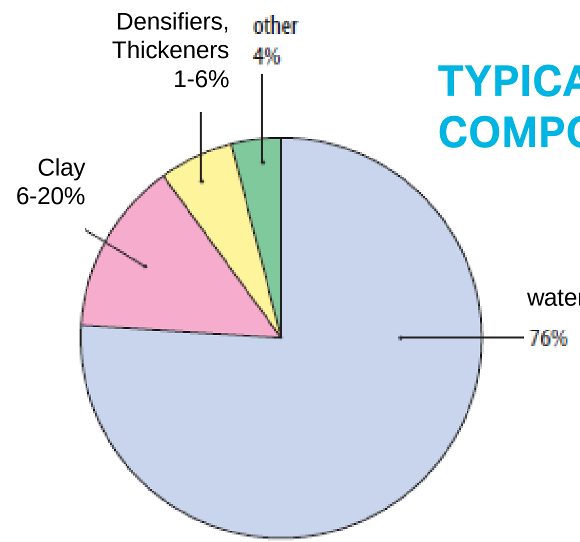


The School of Mud – A Primer

- HDD requires large amounts of drilling mud during all phases
- Five Key Functions:
  - i. Remove drill cuttings from the hole
  - ii. Lubricate and cool the drill bit and assembly
  - iii. Stabilize the borehole and formation
  - iv. Transmit hydraulic energy to the bit
  - v. Suspend cuttings during static periods



TYPICAL MUD COMPOSITION



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The School of Mud – A Primer

- Drilling Mud Requirements:
    i. Optimize one or more of the five key functions
    ii. Enhance productivity by preventing:
        - Slow drilling penetration rates
        - Stuck pipe
        - Lost mud circulation
- No universal fluid that works in all soil conditions; each crossing location requires compromises
    i. Sand: unconsolidated formation requiring good cuttings suspension, lubrication and loss control
    ii. Clay: consolidated formation requiring swelling inhibition and lubrication
    iii. Rock: consolidated/unconsolidated formation requiring good cuttings suspension and lubricity

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The School of Mud – A Primer

- Inadvertent Returns of Drilling Mud:
  i. Drilling mud pumped downhole follows path of least resistance to the surface
  ii. "Hydro-fracturing" or "frac-out" occurs to some degree on most crossings –direction/distance depends on subsurface
  iii. Can occur as a result of: rock fractures, low density soils, poor bore path design
  iv. Release to uplands
  v. Discharge to wetland, stream, or lake - more problematic
  vi. Non toxic, but can have physical impacts on waters

Queens Lake Dam, Williamsburg, VA

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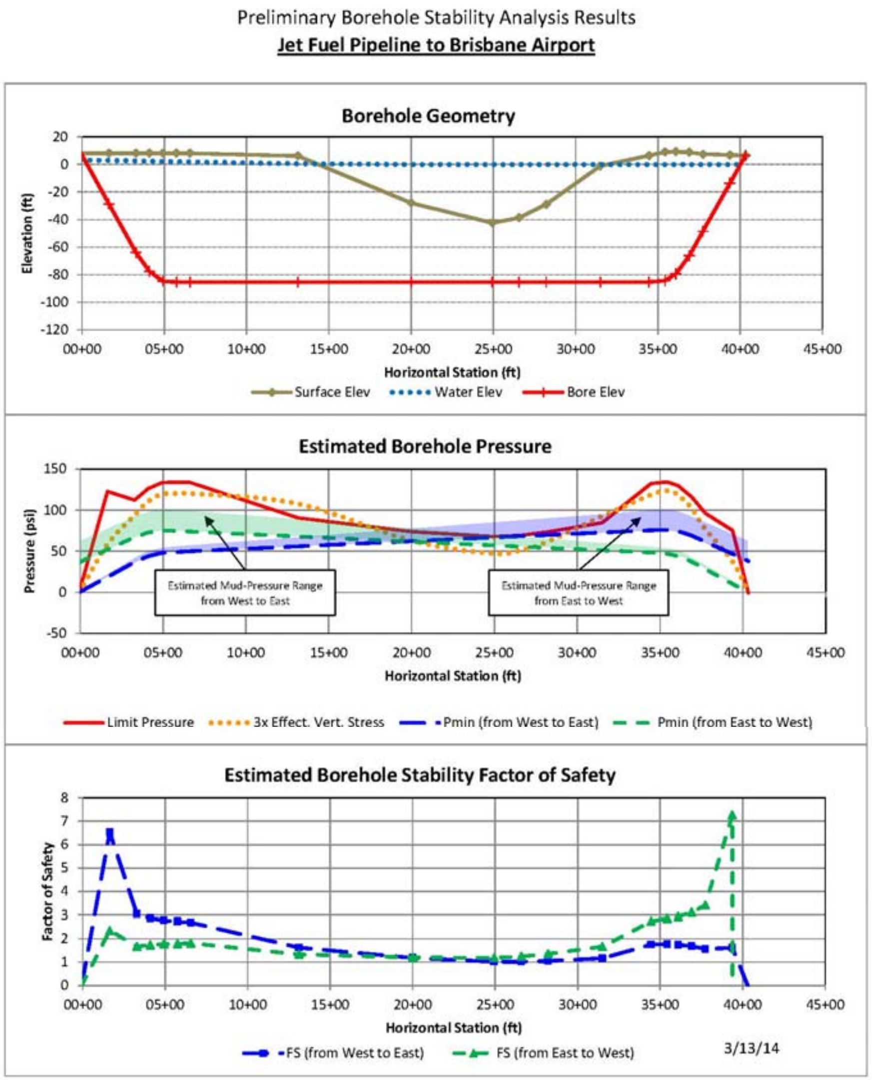
The School of Mud – A Primer

- Mitigation of Inadvertent Returns:
  - i. Pre-drill planning - gather adequate geotechnical data
  - ii. Select a good HDD design – adequate depth, offsets, casings, etc.
  - iii. Quantitative methods to estimate potential for IR (Borehole stability P_{MAX}, P_{MIN})
  - iv. Construction phase – contractor qualifications, full-time mud engineer, downhole pressure monitoring, etc.
  - v. Contingency plans in case – for monitoring during drilling and for spill response.



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Questions ?

Robert A. Marszalkowski, PE

277 Bendix Road, Virginia Beach, VA 23452

+1.757.499.4224

robert.marszalkowski@aecom.com

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